



## ULYSSES AT HIGH LATITUDES: AN OVERVIEW OF RECENT RESULTS

K. G. Marsden\* and F. J. Smith\*\*

\* Space Science Department of ESA, ESTEC, P.O. Box 299,  
2200 AG Noordwijk, The Netherlands

\*\* Jet Propulsion Laboratory, California Institute of Technology,  
4800 Oak Grove Drive, Pasadena, CA 91109, U.S.A.

### ABSTRACT

After its fly-by of the planet Jupiter in February 1992, the Ulysses spacecraft is now in a highly inclined heliocentric orbit that will bring it above the south polar regions of the Sun in September 1994. The high-latitude phenomena observed to date have been strongly influenced by the near-minimum solar activity conditions encountered during this phase of the mission. In late April 1993, when Ulysses was at  $-29^\circ$ S heliographic latitude, the recurrent high speed solar wind stream that had been observed at the location of the spacecraft for 11 consecutive solar rotations underwent a dramatic change. The wind speed in the valleys between successive peaks increased in a single step from  $\sim 420 \text{ km s}^{-1}$  to  $\sim 560 \text{ km s}^{-1}$ . This change in solar wind flow was accompanied by the disappearance at the spacecraft of the magnetic sector structure that had been observed until then. Both these findings are consistent with Ulysses having climbed beyond the latitude of the coronal streamer belt in which is embedded the heliospheric current sheet (HCS). In its subsequent poleward journey, no further evidence for an encounter with the HCS has been seen at Ulysses. Other phenomena observed include the evolution with latitude of corotating interaction regions (CIRs) and their influence on the acceleration of energetic particles, and the characteristics of the solar wind flows emanating from the south polar coronal hole. In this paper, we present details of the above observations. Finally, while the polar passes of the prime mission will take place near solar minimum, an extended mission will bring Ulysses back over the poles near the maximum of the next cycle. A summary of scientific goals for Ulysses at solar maximum is given.

### INTRODUCTION

The primary scientific objective of the joint ESA-NASA Ulysses mission is to characterize for the first time the fields and particles in the inner heliosphere as a function of solar latitude, with particular emphasis on the regions above the solar poles ( $> 70^\circ$ ). The Ulysses scientific investigations encompass studies of the heliospheric magnetic field, heliospheric radio and plasma waves, the solar wind plasma including its minor heavy ion constituents, solar and interplanetary energetic particles, galactic cosmic rays and the anomalous cosmic ray component. Other investigations are directed towards studies of cosmic dust and interstellar neutral gas, as well as solar x-rays and cosmic gamma-ray bursts. Radio science experiments to probe the solar corona and to conduct a search for gravitational waves have also been carried out. An overview of the scientific investigations is given in Table 1.

Because direct injection into a solar polar orbit from the Earth is not feasible, a gravity-assist is required to achieve a high-inclination orbit. As a result, Ulysses was launched at high speed towards Jupiter in October 1990, after being carried into low-Earth orbit by the space shuttle Discovery. Following the fly-by of Jupiter in February 1992, the spacecraft is now travelling southward in an elliptical orbit inclined at  $80.2^\circ$  to the solar equator. In the normal operating mode, the scientific data acquired by the Ulysses instruments are stored by a tape recorder on board the spacecraft for 16 hours and downlinked to the NASA Deep Space Network once a day together with the real time data during an 8-hour tracking pass. The

coverage to date has been excellent, being -97% on average Over the 4s months since launch. This data set represents the most complete set of continuous interplanetary measurements ever recorded. Further details regarding the spacecraft and its scientific investigations can be found in/1/.

TABLE 1 The Ulysses Scientific Investigations

Investigation	Acronym	Principal Investigator	Measurement
Magnetic field	VH MFGM	A. Balogh, Imperial College, London (UK)	spatial and temporal variations of the heliospheric magnetic field: 0.01 to 44000 nT
Solar wind plasma	SWOOPS	J.L. Phillips, Los Alamos National Lab. (USA)	solar wind ions: 260 eV/q 1035 keV/q; solar wind electrons: 0.8 to 860 eV
Solar wind ion composition	SWICS	J. Geiss, Univ. of Bern (CH) G. Gloeckler, Univ. of Maryland (USA)	elemental & ionic-charge composition, temp. and mean speed of solar wind ions; 145 km/s ( $H^+$ ) (o 1350 km/s ( $Fe^{+8}$ ))
Radio and plasma Waves	URAP	R.G. Stone, NASA/GSFC (USA)	plasma waves, solar radiobursts, electron density, electric field plasma waves: 0-60 kHz; radio: 1-940 kHz; magnetic: 10-500 Hz
Energetic particles and interstellar neutral gas	EPAC/GAS	E. Keppler, MPAC, Lindau (D)	energetic ion composition: 80 keV - 15 MeV/n neutral helium atoms
Low-energy ions and electrons	HI-SCALE	L.J. Lanzerotti, AT&T Bell Labs., New Jersey (USA)	energetic ions: 50 keV - 5 MeV energetic electrons: 30-300 keV
Cosmic rays and solar particles	COSPIN	J.A. Simpson, Univ. of Chicago (USA)	cosmic rays and energetic particles ions: 0.3-600 MeV/n electrons: 4-2000 MeV
Solar X-rays and cosmic gamma-ray bursts	GRB	K. Hurley, LJC Berkeley (USA) M. Sommer, MPE, Garching (I)	solar flare X-rays and cosmic gamma-ray bursts: 1S-150 keV
Cosmic dust	DUST	E. Grün, MPK, Heidelberg (D)	dust particles: $10^{-16}$ to $10^{-7}$ g
<b>Radio Science</b>			
Coronal sounding	SCF	M.K. Bird, Univ. of Bonn (D)	density, velocity and turbulence spectra in the solar corona and solar wind
Gravitational Waves	GWE	B. Bertotti, Univ. of Pavia (I)	Doppler shifts in S/C radio signal due to gravitational waves
<b>Interdisciplinary Studies</b>			
Directional discontinuities		M. Schulz, Lockheed Palo Alto Res. Lab. (USA)	
Mass loss and ion composition		G. Noci, Univ. of Florence (I)	
Solar wind outflow		A. Barnes, Ames Res. Center (USA)	
Comets		J.C. Brandt, Univ. of Colorado (USA)	
Cosmic rays		J.R. Jokipii, Univ. of Arizona (USA)	
shocks		C.P. Sonett, Univ. of Arizona (USA)	

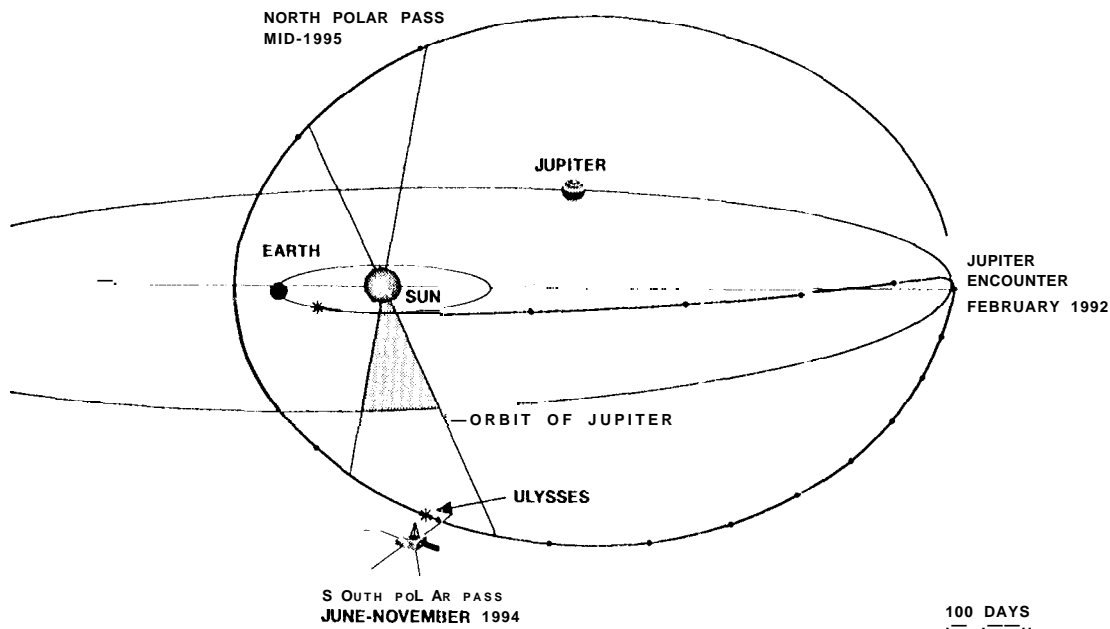


Fig. 1. The Ulysses spacecraft trajectory, viewed from above the ecliptic plane.

#### THE ULYSSES POLAR PASSES

The Ulysses polar passes are defined to be those periods during which the spacecraft is above  $70^\circ$  heliographic latitude in either hemisphere. The mission was designed to maximise the total duration of the polar passes, with a minimum requirement of 150 days. In fact, the actual mission performance is significantly better than this and the spacecraft will spend a total of 234 days above  $70^\circ$ . The first polar pass will take place in the southern hemisphere, a consequence of Jupiter's position with respect to the solar equator at the time of the fly-by. Starting 26 June 1994, Ulysses will spend 132 days at southern heliographic latitudes greater than  $70^\circ$ , reaching a maximum latitude of  $80.2^\circ$  in mid-September. The first polar pass will end on 5 November 1994. In contrast to the initial climb from low to high latitudes, which took more than 2 years and covered a range of radial distances (5.4 to 2.3 AU), the south pole-to-equator segment of the trajectory is completed in only 6 months and at a more constant heliocentric radius. The second (northern) polar pass takes place almost exactly one year after the first, and is slightly shorter in duration (102 days). The end of the second pass, on 29 September 1995, marks the end of the prime mission, although firm plans exist to continue mission operations for a full second orbit (see later in this article). Figure 1 is a schematic of the Ulysses trajectory. It should be noted that the out-of-ecliptic trajectory enables a survey to be made of all *magnetic* latitudes, since the inclination of the Sun's magnetic dipole axis with respect to its rotation axis is generally greater than  $10^\circ$ .

#### RESULTS FROM THE FIRST MID-LATITUDE SURVEY ( $15^\circ$ – $55^\circ$ S)

In this section, we present a selection of the results obtained in the period following Jupiter fly-by up to the start of the first polar pass, with particular emphasis on the mid-latitude region between approximately  $15^\circ$  and  $55^\circ$  S. This period is characterised by a general decline in solar activity that followed the more dynamic conditions encountered by Ulysses during its transit from Earth to Jupiter in 1991/25. As a general remark, it is important to realise that the polar passes of the prime mission, while providing new and unique information concerning the three-dimensional nature of the heliosphere, will focus rather strongly on phenomena related to solar minimum. Continuing the mission for a second solar orbit, on the other hand, will enable high-latitude measurements to be made at solar maximum, leading to a more complete picture as discussed later in this paper.

### Solar Wind Plasma and Heliospheric Magnetic Field

An important feature of the global structure of the heliosphere is the heliospheric current sheet (HCS) that separates interplanetary magnetic field of opposite polarity. The HCS is the outward projection of the Sun's magnetic equator and associated coronal streamer belt, and its form is known to change from being highly complex at solar maximum to being relatively simple at solar minimum. A key parameter is the average tilt of the HCS with respect to the Sun's rotation axis, which in turn is related to the tilt of the Sun's magnetic dipole axis with respect to the rotation axis. The current sheet is known to become flatter and more equatorial near solar minimum (e.g. [3]). HCS crossings at the location of Ulysses ceased in April-May 1993 at a heliographic latitude of  $\sim 30^\circ$  south, a consequence of the spacecraft's poleward motion [4]. Prior to Ibis, beginning in July 1992, a recurrent high-speed stream whose source was an equatorward extension of the polar coronal hole in the southern solar hemisphere dominated the solar wind plasma conditions at Ulysses [5,6].

TABLE 2 Key Events During Ulysses' First Heliographic Latitude Scan.

Time	Latitude	R (AU)	Observation	Reference
early Jul. '92	$13^\circ$ s	5.3	First observation of recurrent high-speed stream	[6]
late Apr. '93	$29^\circ$ S	4.8	Step-like increase in min. SW speed from $\sim 420$ to $560 \text{ km s}^{-1}$	[6]
May '93	$30^\circ$ s	4.7	Disappearance of magnetic sector structure	[4]
late Jun. '93	$33.6^\circ$ S	4.6	Last forward shock (CIR)	[7]
late Jul./early Aug. '93	$36^\circ$ S	4.4	Constant immersion in SW from polar coronal hole	[7]
early Mar. '94	$55.5^\circ$ s	3.4	Last reverse shock (CIR)	[10]

The passage below the HCS was accompanied by a jump in the minimum solar wind speed from  $\sim 400 \text{ km s}^{-1}$  to  $\sim 550 \text{ km s}^{-1}$  [6], the maxima remaining relatively unchanged at between  $750$  and  $800 \text{ km s}^{-1}$ . A further jump in minimum speed, to approximately  $700 \text{ km s}^{-1}$ , occurred in August 1993, after which time the wind speed profile has shown few, if any, recurrent features. When normalised to the same radial distance, the density, speed, mass flux and ram pressure observed by Ulysses over the latitude range  $36^\circ$  to  $60^\circ$ S were all rather constant, implying that the spacecraft was immersed in pure high-speed wind. Observations of the photospheric magnetic fields and the inferred coronal hole boundaries for the period corresponding to the Ulysses measurements indicate that the corona did not evolve significantly during 1993, implying that the solar wind features seen at Ulysses were primarily the result of the spacecraft's increasing southerly latitude [7].

The 1993/94 mid-latitude survey has been particularly successful in revealing the latitudinal evolution of solar wind stream interaction regions [8]. According to the model of Pizzo and Gosling [11], the tilt of the coronal streamer belt (and the underlying solar dipole) with respect to the Sun's rotational axis causes a poleward propagation of the reverse shock associated with a corotating interaction region (CIR) and an equatorward propagation of the CIR forward shock in either hemisphere. Seen from a spacecraft travelling southward at constant or decreasing radial distance, this leads to a gradual disappearance of CIR-related forward shocks, while reverse shocks, although becoming progressively weaker, continue to be observed. This behaviour has now been put on a firm observational footing by Ulysses. The last forward shock from a CIR was recorded at  $33.6^\circ$  south, while reverse shocks have persisted beyond  $45^\circ$  [7]. It should also be noted that reverse shocks associated with CIRs continue to propagate to high latitudes be-

yond 5 AU /12/. This means that a spacecraft at high latitude, while not observing a reverse shock locally, may nevertheless be magnetically connected to a reverse shock existing at the same latitude farther out from the Sun. This phenomenon will be discussed in more detail in the section dealing with energetic particle observations.

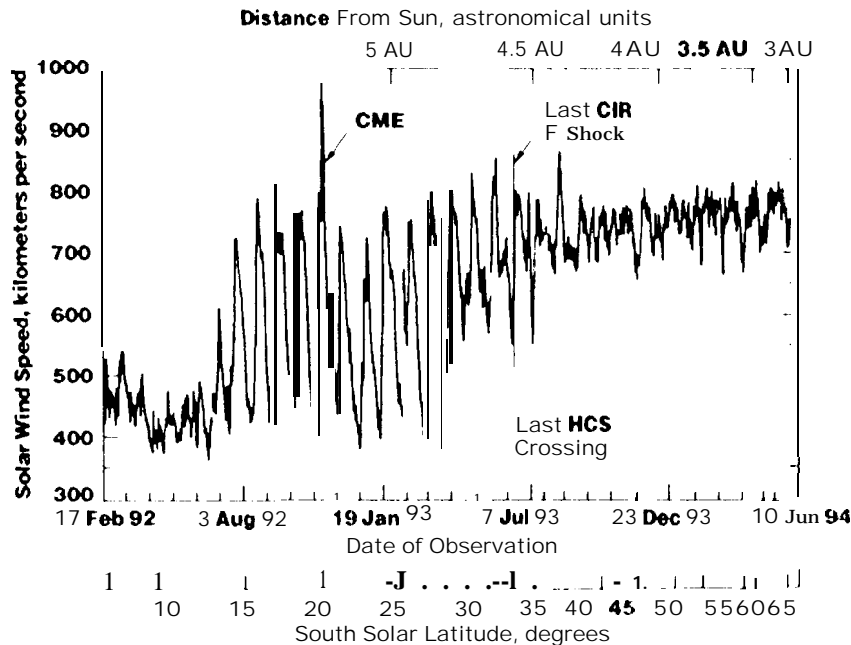


Fig. 2. Solar wind speed as measured by the SWOOPS experiment on board Ulysses (from /10/).

while many of the solar wind structures observed at mid-to-high latitudes by Ulysses have been of the cometary kind associated with the long-lived high-speed stream discussed above, a number of coronal mass ejections (CMEs) have also been detected in the high-latitude solar wind /9/. Eight such events were recorded between  $31^\circ$  and  $55^\circ$  south, one of which was directly associated with a CME event observed by the soft X-ray telescope on the Yohkoh satellite. In addition to being the first *in-situ* measurements of high-latitude CMEs in the solar wind, the Ulysses data have revealed an important feature of such structures, namely that they are propagating at the same speed as the ambient fast solar wind plasma. Recalling that CMEs in the solar wind in the ecliptic show similar behaviour, Gosling and co-workers suggest /9/ that all CMEs are subject to the same basic acceleration process as the normal solar wind, regardless of the latitude at which they leave the Sun.

The Ulysses solar wind ion charge state abundance measurements can be used to infer the electron temperature in the corona at which the distribution of observed charge states for a given element becomes "frozen-in" /13/. Galvin and co-workers report the first such ionization temperature determinations for Oxygen, Silicon and iron ions originating in the south polar coronal hole /14/. The inferred coronal temperature, ranging from  $1.1$  to  $1.5 \times 10^6$  K, is lower than that of the normal quiet Sun, and the measurements imply an electron temperature gradient over the range of freezing-in altitudes which is quite small.

An important question to be addressed by Ulysses is how well the large-scale configuration of the heliospheric magnetic field at high latitudes matches the predictions of the model first proposed by Parker /15/ in which the combined effects of solar rotation and the radial expansion of the solar wind into which the field is "frozen" lead to the familiar Archimedean spiral pattern. According to this picture, near-equatorial field lines will wrap around cones of half-angle corresponding to the colatitude of their foot points at the Sun, becoming radial over the poles. Initial results from the Ulysses magnetometer experiment indicate that the average magnetic field exhibits the expected pattern, with the ratio of the azimuthal to radial

components decreasing as  $\sin\theta$  where  $\theta$  is the colatitude. However, the mid-latitude field in the southern hemisphere is less tightly wound than predicted /16/. The origin of this effect is not yet understood.

A possible modification to the Parker model has been proposed by Jokipii and Kota /17/, who suggest that the simple radial polar fields referred to above would be significantly modified if there are transverse perturbations present in the source field at the Sun. These transverse components, even though small at the source, will decrease less rapidly with distance than the radial component and will tend to dominate at large (10s of AU) distances. If this should indeed be the case, it would have a profound effect on the modulation of cosmic rays, whose entry into the inner heliosphere depends critically on the configuration of the polar fields. Smith and co-workers /18/ report the existence of large-amplitude, long-period (10 to 20 hours) Alfvén waves in the Ulysses field measurements associated with southern polar coronal hole flows that could represent the waves discussed in /17/.

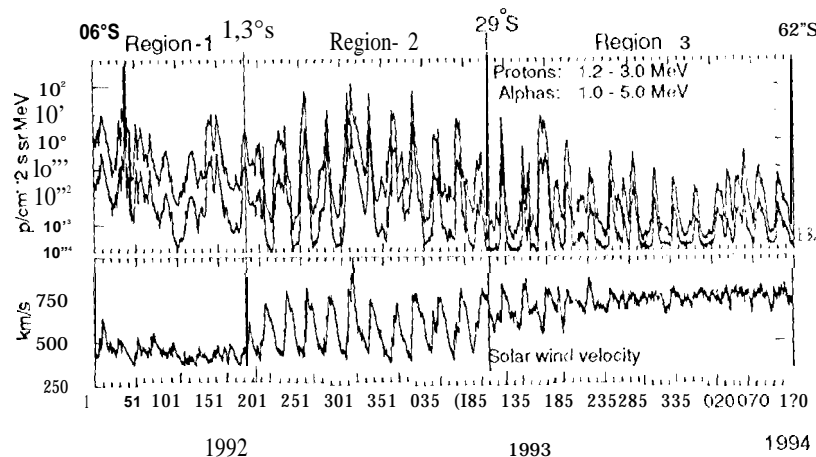


Fig. 3. Intensity of 1.2 - 3.0 MeV protons and 1.0 - 5.0 MeV/n alpha particles as measured by the COSPIN/LET experiment on board Ulysses (upper panel), together with the solar wind velocity from SWOOPS (from /19/).

### Energetic Particles

For a period of approximately one year starting in early July 1992, Ulysses encountered a recurrent high-speed solar wind stream and associated corotating stream interaction regions, as discussed above. The forward and reverse shocks bounding CIRs are known to accelerate ions to MeV energies near the ecliptic, and a key objective of the Ulysses observations is to study the latitude dependence of the acceleration process. Given the disappearance of forward shocks at the spacecraft at latitudes poleward of  $\sim 34^\circ\text{S}$  and the general weakening of the reverse shocks /7/, it is not unreasonable to suppose that the intensity of accelerated ions will show a rapid decrease at mid- to high latitudes, with no recurrent increases seen beyond the latitude of the last-observed reverse shock. In fact, the situation as revealed by the Ulysses data is more complex, with recurrent increases of  $\sim 1$  MeV ions continuing to be seen at the highest latitudes reached 10 days /19,20/.

Comparing the features of intensity increases of  $\sim 0.5$  MeV ions and  $\sim 40$  keV electrons recorded by the HI-SCALE instrument on Ulysses, Sinnott and co-workers /20/ find that at latitudes above  $\sim 30^\circ\text{S}$ , there is a progressive delay between the time of maximum ion intensity and maximum electron intensity. While the ion increases tend to be temporally associated with the reverse shock and have maximum intensities that decrease with latitude, the electron events often peak as much as several days after the passage of the reverse shock with intensity maxima that are roughly latitude-independent. These authors suggest that both populations are accelerated at the reverse shock, the difference in timing arising from the fact that, in contrast to the ions, the electrons are accelerated non-locally /20/. Several days after the CIR has passed Ulysses, the spacecraft is magnetically connected to the reverse shock at a much larger radius where the shock strength is higher. Since the accelerated electrons travel much faster than the

shock, (they are not confined to the CIR and propagate back in toward the Sun where they undergo magnetic mirroring. In this way, the electrons are able to have multiple shock encounters, thereby increasing the acceleration efficiency.

### Cosmic Rays

The idea that galactic cosmic rays arrive relatively unimpeded over the poles is an intriguing concept that has been debated for many years. To test this idea directly is one of the key objectives of the Ulysses mission. In addition to the almost scatter-free propagation along the supposed near-radial, weak polar magnetic field that forms the basis for this idea, particle drift motion is also favourable to the transport of positively charged cosmic rays from the poles to the heliospheric current sheet in the current phase of the solar magnetic cycle. The expectation, therefore, was that Ulysses would find a significant positive latitudinal gradient. A major surprise from the data obtained to date is that this gradient appears to be absent, at least down to  $\sim 60^\circ$  south [21]. Measurements at even higher latitudes, to be obtained during the polar passes, will provide a definitive answer. The lack of a latitudinal gradient, if confirmed, may not necessarily imply a failure of the basic theory of cosmic ray transport. Rather, it may point to an inadequacy in our quantitative knowledge of the parameters entering the equations. The detailed physics entering into the specification of the spatial diffusion tensor, in particular, requires better understanding [22].

Another feature of the cosmic ray data that was not expected is the persistence of a "27-day" periodic modulation even after the spacecraft moved poleward of the maximum latitude at which CIR-like structure was observed locally in the solar wind [23,24]. As in the case of the energetic particles, the high-latitude field lines along which the cosmic rays reach Ulysses must connect to the CIRs responsible for the modulation farther out in the heliosphere, where the latitudinal extent of the corotating structure has increased. McKibben and co-workers show that the modulation at Ulysses is in phase with similar variations seen at IMP-8 at 1 AU, pointing to the global nature of the modulating region [23].

### ULYSSES AT SOLAR MAXIMUM

The phenomena being studied by the Ulysses mission are strongly influenced by the 11-year solar activity cycle. The primary mission, defined to end in September 1995, extends over about half of the solar cycle. Since the orbital period of the sun-centered, out-of-ecliptic orbit is 6.2 years, continuing the mission for another orbit makes coverage of the second half of a cycle possible. The polar passes during the prime mission occur during the descending phase of the solar cycle, close to solar minimum. The polar passes during the second orbit, on the other hand, will take place in 2000 and 2001, close to solar maximum (see Table 3).

The period beyond 1995 will be of particular importance, since the Ulysses mission, then at high solar latitude, will form an important complement to ESA's SOHO and NASA's WIND missions. SOHO will carry an extensive complement of solar experiments dedicated to studying the sun's corona and the solar wind. WIND will provide continuous monitoring of the heliospheric magnetic field, waves and particles in the ecliptic plane at 1 AU.

Following the north polar pass in 1995, Ulysses will descend in latitude towards the orbit of Jupiter (aphelion in 1998, see Table 3). The outbound leg of the trajectory provides an opportunity to survey the latitude range between  $70^\circ$  and  $0^\circ$  at solar distances between 2.2 and 5.4 AU for a second time. In contrast to the first (1992-1994) inbound *ascent* in latitude, the outbound *descent* in latitude (1996-1998) will occur at solar minimum conditions or in the early rising phase of the next solar cycle. The spacecraft will spend a relatively long time near  $10^\circ$  when both the solar latitude and radial distance are changing slowly. From June 1997 to June 1998, Ulysses will be within  $\pm 10^\circ$  of the solar equator, and from May 1997 to April 1999 at heliocentric distances greater than 5 AU. This interval will provide an opportunity to study time variations free of concern about spatial variations.

TABLE 3 Mission Summary For Ulysses' Second Solar Orbit

Event	Year	Mon	Day	
Aphelion (5.4 AU)	1998	04	17	"
3rd Polar Pass (S)				
start	2000	09	03	
max. latitude ( $80.2^\circ$ )	2000	11	27	
end	2001	01	16	
Perihelion (1.3 AU)	2001	05	26	
4th Polar Pass (N)				
start	2001	09	03	
max. latitude ( $80.2^\circ$ )	2001	10	13	
end of mission	2001	12	12	

#### Scientific Goals of the Ulysses Mission During the Period 1995 to 2001

During solar maximum, the conditions encountered by Ulysses are expected to be dramatically different, especially in the polar regions, from those during the prime mission. The polar cap magnetic fields will be in the process of vanishing and then reversing polarity. Poleward-drifting unipolar magnetic regions will have the opposite polarity and will tend to reduce rather than enhance the polar fields. The HCS, which has a low inclination at solar minimum, will be highly inclined and may consist of multiple sheets.

This complex and dynamic field topology will have important consequences for the solar wind, solar energetic particles and cosmic rays. It will pose basic questions to be answered:

Where do the heliospheric magnetic fields and solar wind originate? Are the large-scale properties of the solar wind, particularly the speed and density, still correlated with distance to the current sheet? What will be the magnetic topology of CMFs encountered at high latitude? The solar wind, being closely coupled to coronal magnetic fields, is also expected to undergo drastic changes. CMFs are expected to dominate corotating structure even at high latitudes. Will the flow from high polar caps be correspondingly irregular? Will shocks be present? Will high speed streams still originate from coronal holes?

Galactic cosmic rays will be strongly modulated. How will their properties (e.g. intensity) differ from the poles to the equator? Will it be possible to determine the relative importance of drifts and merged interaction regions in the modulation process? What role does the HCS (or sheets) play? Can the anomalous cosmic ray component penetrate into the polar regions? At lower energies, the properties of solar energetic particles will probably be very different. The increased solar activity will ensure a large number of flares, including some that are very intense. Will particles accelerated in flares or CME shocks be detected at high latitudes? Will evidence for local acceleration at transient shocks be found in the polar regions?

The above list of topics is clearly not exhaustive. Nevertheless, it demonstrates that continuation of Ulysses for a second solar orbit effectively constitutes a new mission with unique scientific goals that will not be addressed by any other mission in the foreseeable future. Furthermore, the inherent possibility of comparing of the polar heliosphere at solar minimum and solar maximum using the *same set of instruments* is an added bonus of considerable value.

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## REFERENCES

1. K.-P. Wenzel, R.G. Marsden, D.E. Page and E.J. Smith, The Ulysses mission, *Astron. Astrophys. Suppl. Ser.* 92, 207 (1992).
2. E.J. Smith and K.-P. Wenzel, Introduction to the Ulysses encounter with Jupiter, *J. Geophys. Res.* 98, 21, 111 (1993).
3. S.T. Suess, D.J. McComas and J.T. Hocksema, Fluctuations of the heliospheric current sheet tilt: 1992-1996, *Geophys. Res. Lett.* 20, 161 (1993).
4. E.J. Smith, M. Neugebauer, A. Balogh, S.J. Bame, G. Erdös, R.J. Forsyth, B.E. Goldstein, J.L. Phillips and B.T. Tsurutani, Disappearance of heliospheric sector structure at Ulysses, *Geophys. Res. Lett.* 20, 2327 (1993).
5. A. Balogh, G. Erdös, R.J. Forsyth and E.J. Smith, The evolution of the interplanetary sector structure in 1992, *Geophys. Res. Lett.* 20, 2331 (1993).
6. S.J. Bame, B.E. Goldstein, J.T. Gosling, J.W. Harvey, D.J. McComas, M. Neugebauer and J.L. Phillips, Ulysses observations of a recurrent high-speed stream and the heliomagnetic streamer belt, *Geophys. Res. Lett.* 20, 2323 (1993).
7. J.L. Phillips, A. Balogh, S.J. Bame, B.E. Goldstein, J.T. Gosling, J.T. Hocksema, D.J. McComas, M. Neugebauer, N.R. Sheeley, Jr. and Y.-M. Wang, Ulysses at 50° South: constant immersion in the high-speed solar wind, *Geophys. Res. Lett.* 21, 1105 (1994).
8. J.T. Gosling, S.J. Bame, D.J. McComas, J.L. Phillips, V.J. Pizzo, B.E. Goldstein and M. Neugebauer, Solar wind corotating interaction regions out of the ecliptic plane: Ulysses, *Space Sci. Rev.* 72, in press (1994).
9. J.T. Gosling, S.J. Bame, D.J. McComas, J.L. Phillips, A. Balogh and K.T. Strong, Coronal mass ejections at high heliographic latitudes: Ulysses, *Space Sci. Rev.* 72, in press (1994).
10. D.J. McComas, J.L. Phillips, S.J. Bame, J.T. Gosling, B.E. Goldstein and M. Neugebauer, Ulysses solar wind observations to 56° south, *Space Sci. Rev.* 72, in press (1994).
11. V.J. Pizzo and J.T. Gosling, 3-D simulation of corotating interaction regions observed by Ulysses near the top of the heliospheric current sheet, *Geophys. Res. Lett.* in press (1994).
12. J.T. Gosling, S.J. Bame, D.J. McComas, J.L. Phillips, V.J. Pizzo, B.E. Goldstein and M. Neugebauer, Solar wind corotating stream interaction regions out of the ecliptic plane: Ulysses, *Space Sci. Rev.* 72, in press (1994).
13. G. Gloeckler, J. Geiss, H. Balsiger, P. Bedini, J.C. Cain, J. Fischer, L.A. Fisk, A.B. Galvin, F. Gliem, D.C. Hamilton, J.V. Hollweg, F.M. Ipavich, R. Joos, S. Livi, R. Lundgren, U. Mall, J.F. McKenzie, K.W. Ogilvie, F. Ottens, W. Rieck, E.O. Turner, R. v. Steiger, W. Weiss, B. Wilken, U.T. Cobbley, A.N. Dan, The solar wind ion composition spectrometer, *Astron. Astrophys. Suppl. Ser.* 92, 267 (1992).
14. A.B. Galvin, F.M. Ipavich, C.M.S. Cohen, G. Gloeckler and R. v. Steiger, Solar wind charge states measured by Ulysses/SWICS in the south polar hole, *Space Sci. Rev.* 72, in press (1994).

15. E.N. Parker, Dynamics of the interplanetary gas and magnetic fields, *Astrophys. J.* 128, 664 (1958),
16. R.J. Forsyth, The high latitude heliospheric magnetic field, *Space Sci. Rev.* 72, in press (1994).
17. J.R. Jokipii and J. Kóta, The polar heliospheric magnetic field, *Geophys. Res. Lett.* 16, 1 (1989).
18. E.J. Smith, M. Neugebauer, A. Balogh, S.J. Bame, R.P. Lepping and B.T. Tsurutani, Ulysses observations of latitude gradients in the heliospheric magnetic field: radial component and variances, *Space Sci. Rev.* 72, in press (1994).
19. T.R. Sanderson, R.G. Marsden, K.-P. Wenzel, A. Balogh, R.J. Forsyth and B. E. Goldstein, High-latitude observations of energetic ions during the first Ulysses polar pass, *Space Sci. Rev.* 72, in press (1994).
20. J. G.M. Simnett and E.C. Roelof, Reverse shock acceleration of electrons and protons at mid-heliolatitudes from 5.3 AU -3.8 AU, *Space Sci. Rev.* 72, in press (1994).
21. R.B. McKibben, J.J. Connell, C. Lopate, J.A. Simpson and M. Zhang, Cosmic ray modulation in the 3-D heliosphere, *Space Sci. Rev.* 72, in press (1994).
22. M.A. Lee, Ulysses' race to the pole, : symposium summary, *Space Sci. Rev.* 72, in press (1994).
23. R.B. McKibben, J.A. Simpson, M. Zhang, S.J. Bame and A. Balogh, Ulysses out-of-ecliptic observations of '127-day' variations in high energy cosmic ray intensity, *Space Sci. Rev.* 72, in press (1994).
- 24.11. Kunow et al., 1 high energy cosmic ray nuclei results on Ulysses: 2. Effects of a recurrent high speed stream from the southern coronal hole, *Space Sci. Rev.* 72, in press (1994).
25. K.-P. Wenzel and E.J. Smith, The Ulysses mission: in-ecliptic phase, *Geophys. Res. Lett.* 19, 123S (1992).